Laser Science & Technology

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Electro-Optic Q-Switch for High-Average-Power, High-Repetition-Rate Lasers

High-energy, multipass laser architectures require electro-optic switches to stop unwanted laser oscillation (laser pulses that occur before and after the main laser pulse). In effect, an electronically controlled shutter is required, a shutter that can respond in a time frame as short as the desired laser pulse. An electro-optic crystal (also known as a Q-switch)—essentially a crystal that has a voltage-dependent refractive index—is the only electrically driven device that can respond in a time frame as short as a nanosecond. The issue with existing electro-optic cell architectures is that heat from the laser beam itself prevents the electro-optic cell from functioning effectively at high-average-power because as the crystal is heated, the switch begins to let light "leak" due to thermal birefringence-induced depolarization of the laser beam. The National Ignition Facility utilizes a plasma electrode Pockels cell (PEPC) for efficient energy extraction of the final amplifier. The PEPC is an example of a high-peak-power electro-optic Q-switch designed specifically for laser operation at low repetition rate.

The Mercury laser under development at LS&T is a prototype of a high-average-power fusion laser driver, designed to probe the fundamental interactions of light and matter. The Mercury laser system will produce 100-J pulses at a repetition rate of 10 Hz, or an average power of 1,000 W. Experimental

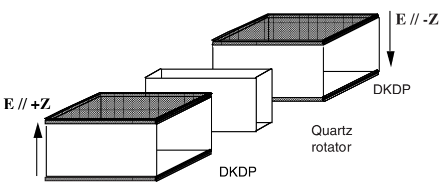

Figure 1. Thermally induced birefringence (light leakage) that occurs in the first crystal is cancelled in the second crystal.

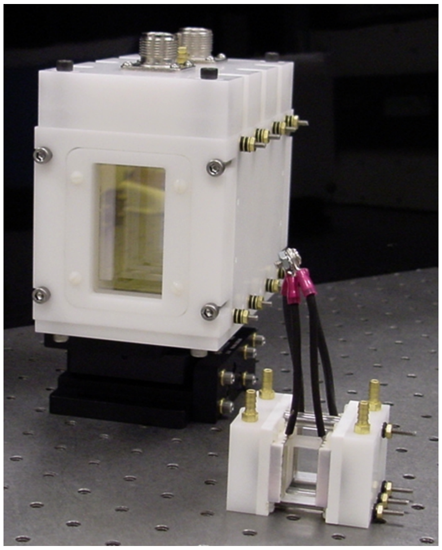

Figure 2. High-average-power KD_2PO_4 (DKDP) electro-optic Q-switches: large-aperture (3.5 cm x 6 cm) and with smaller-aperture (1.5 cm x 3 cm).

fusion laser system architectures, such as the Mercury laser, require the electro-optic cell to let light through when desired and prevent the laser system from being damaged by unwanted amplifier laser light.

A short-pulse laser oscillator typically consists of a high-reflectivity mirror, a gain medium, a partially reflecting output mirror, and an electro-optic Q-switch and polarizer combination which acts as a mirror with electrically controlled reflectivity. The ideal electro-optic Q-switch and polarizer would act with only two states: high reflectivity and zero reflectivity. During operation, voltage initially applied to the Q-switch makes the effective mirror reflectivity low, so that no laser oscillation can take place. Gain is stored in the laser rod during this time. When the laser gain reaches its maximum, the electro-optic Q-switch voltage is switched off, creating a high-reflectivity mirror. Because of the high gain, laser oscillation rapidly builds up, and a short optical pulse is emitted through the output mirror. However, at average powers above 30 W, the electro-optic Q-switch heats up (from the intracavity laser beam itself) and effectively the Q-switch behaves as a lossy mirror, whose loss

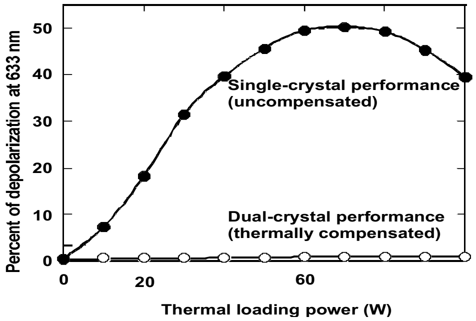

Figure 3. The thermally compensated electro-optic Q-switch shows almost no depolarization loss compared with a single-crystal, uncompensated Q-switch.

attenuates the gain that can be stored, leading to longer optical pulse widths and lower energy extraction efficiency.

Traditional electro-optic Q-switches use a single electro-optic crystal and exhibit a temperature-dependent loss. Our thermally compensated electro-optic Q-switch dramatically reduces this loss by greater than ten times. A schematic of the switch assembly is shown in Figure 1. In this configuration the leakage or depolarization loss exhibited by the first crystal is canceled by propagation through the polarization rotator and second identical crystal. The fully assembled Q-switches are shown in Figure 2. Their dramatic performance is shown in Figure 3. The depolarization loss is shown as a function of heating for both a single-crystal and a dual-crystal electro-optic Q-switch. When the depolarization loss approaches 10%, the switch has effectively failed. Our thermally compensated Q-switch shows less than 1% loss up to the testing limit of 100 W of laser light.

We anticipate the device to operate up to 300 W, ten times greater than the equivalent commercially available electro-optic Q-switch. This type of large-aperture electro-optic Q-switch will be especially useful for the next generation of high-average-power lasers that have applications in machining, laser materials processing, and probing the interaction of light with matter in fusion experiments.

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